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U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TCREC TECHNICAL REPORT 62-23

EXPLORATORY FULL-SCALE GROUND AND FLIGHT TEST EVALUATION OF THE ROBERTSON ULTRA-LOW SPEED FLIGHT CONTROL SYSTEM

Project 9R38-11-009-10
Contract DA 44-177-TC-702

May 1962

prepared by:

FT, INC.
rth, Texas

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Skycraft Report SRQ-4

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for

U. S. ARMY TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

FOREWORD

The application of CANARD surfaces as an aerodynamic device for achieving control during slow flight is discussed by the contractor in this report.

The stability and the control forces generated on the experimental Model SRQ aircraft with and without the contractor-developed Ultra Low Speed Control System (ULS) were recorded during ground and flight tests.

Flight evaluation of the ULS Control Surfaces mounted on the Model SRQ aircraft was made by Government test pilots.

The discussion, conclusions, and recommendations of the report reflect the views of the contractor and do not necessarily represent the position or plans of the Department of the Army.

The U. S. Army Transportation Research Command concurs that the ground and flight tests demonstrate that the ULS system of immersing an additional set of control surfaces in the propeller slipstream is an effective means of providing improved control at low speed and where applicable should be considered in designs for future aircraft. Since control surfaces mounted ahead of the center of gravity are basically destabilizing, many factors must be taken into account prior to application, such as relative size of forward surfaces to aft surfaces, hinge moment characteristics, and maximum design speed.

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CONTENTS

SUMMARY

This report presents the results of an exploratory full-scale ground and flight test evaluation of the stability, control, performance, handling, and maintenance characteristics of the Robertson Ultra-Low-Speed Control System (U. L. S.). This system is designed to generate the high control powers required for V/STOL landing and take-off maneuvers.

The U. L. S. consists of a small set of aerodynamic control surfaces placed immediately behind the propeller disk and permanently connected to the airplane's conventional flight control system. Being completely immersed in the propeller slipstream, these surfaces operate on the principle of using slipstream dynamic pressure rather than free stream dynamic pressure for the generation of control power.

The results of this program showed that, at 40 m. p. h., the U. L. S. increased pitch, yaw, and roll control powers to 256 percent, 280 percent, and 250 percent, respectively, of basic airplane values. This increase also reduced the airplane's minimum speed from a control-limited 40 to a power-limited 20 m. p. h. with an attendant 50 percent reduction in landing and take-off distance. Glide angle was increased from 10° to 20° through installation of the new system.

The U. L. S. installation did not appreciably affect stability or handling qualities, and caused no "oversensitivity" at maximum speed (168 m. p. h.).

Test results indicate that the rudimentary U. L. S. system tested is a light, simple, and inexpensive way of generating the powerful low-speed control moments required for V/STOL operation.

CONCLUSIONS

1. The U. L. S. is capable of generating pitch, roll, and yaw control moments down to zero forward speed, its control power capability depending on slipstream dynamic pressure rather than airplane forward speed.

2. For STOL aircraft with minimum airspeeds between 20 and 50 m. p. h., installation of the U. L. S. system can increase low-speed maneuverability by several hundred percent. For the test aircraft, the increased controllability provided by the U. L. S. installation reduces the minimum airspeed from a control-limited 40 to a power-limited 20 m. p. h., with an attendant 50 percent reduction in landing and take-off distance. Glide angle is increased from 10 to 20 degrees, thus further increasing the operational usefulness of the aircraft.

3. Although the U. L. S. produces markedly increased control moments at low airspeeds, its installation provides no control "oversensitivity" at cruising or high speeds. U. L. S. handling characteristics generally duplicate those of the basic airplane, with no unusual flat spots, nulls, time lags, or peculiar stick force gradients being developed.

4. The fact that the U. L. S. installation has no appreciable effect on high-speed stability or handling characteristics makes it attractive for use on existing aircraft whose performance potential cannot be fully realized because of a low-speed control deficiency.

5. For operations up the backside of the power-required curve, the effectiveness of the U. L. S. system actually increases since the thrust horsepower required increases as forward speed decreases; this holds true all the way down to zero forward speed.

6. The U. L. S. as tested is a light, simple, and effective means of generating low-speed control for V/STOL aircraft.

RECOMMENDATIONS

1. Since the test aircraft is power-limited to a minimum airspeed of 20 m. p. h. but is otherwise capable of operating at even lower speeds, it is recommended that the test program be extended to incorporate the installation of at least an 800-horsepower turboprop power plant. This would permit penetration of a flight regime hitherto closed to relatively simple fixed-wing aircraft, and should provide a wealth of test data of value to many other current V/STOL investigations.

2. The flight test program indicated that ground-test results could be applied with good accuracy to flight performance; accordingly, a Phase II ground-test program should be undertaken to optimize U. L. S. configurations for the various power plants programmed for new V/STOL aircraft. This program would be accompanied by a wind tunnel test series systematically investigating the stability and control characteristics of various U. L. S. configurations. The model for these tests has already been completed.

3. Since the basic L-19 is potentially capable of performance that might make it attractive as an interim STOL aircraft, it is recommended that a modernized L-19 be developed by modifying a standard L-19 through installation of the U. L. S. for low-speed control, use of a high-drag, double-slotted flap for steep level-attitude approaches, and incorporation of a tricycle landing gear for optimum short-field performance.

4. Since the U. L. S. system is particularly attractive for use in multi-propeller V/STOL aircraft where the lateral disposition of propellers maximizes U. L. S. roll power (or in the case of a tilt wing, yaw power), consideration should be directed toward testing a U. L. S. on a control-limited aircraft of this type.

INTRODUCTION

The objective of this report is to present the results of an exploratory Ground- and Flight-Test Investigation of a new type of control system for use on V/STOL aircraft. This new system, designated the Robertson Ultra-Low-Speed Control System (U. L. S.), operates on the principle of using propeller slipstream dynamic pressure rather than airplane dynamic pressure as the energy source for control-power generation.

Since the present investigation is a feasibility study directed to yielding indicative results rather than maximum capabilities, no serious attempt was made to explore fully the ultimate control power potential of the U. L. S.

The heavily flapped and slatted Robertson "SKYSHARK" STOL aircraft was used as a test bed throughout the program.

BACKGROUND

The advent of high power/weight ratio power plants makes possible the development of an entirely new generation of fixed-wing aircraft capable of V/STOL performance. The attractiveness of these aircraft lies in their versatility; they are generally capable of operating with airplane-type speed and economy into restricted areas hitherto accessible only to the relatively slow and expensive helicopter. However, to achieve this V/STOL performance, these aircraft must be capable of flying at extremely low airspeeds in order to minimize the space required for their landing and take-off operations.

While the low airspeeds necessary to V/STOL performance have been achieved in a number of aircraft, serious problems have developed in attempting to control these aircraft at low speeds. This control problem embraces three factors:

1. Control powers of conventional flight-control surfaces vary as the square of the airplane's forward speed; thus, at 30 m. p. h., only one-fourth as much controllability exists as is available at 60 m. p. h. The effectiveness of conventional controls that are entirely adequate for airplane flight at 60 m. p. h. decays so rapidly with decreasing air speed as to render them virtually useless in the vital 0 to 30 m. p. h. speed range normally associated with V/STOL landing and take-off maneuvers.

2. Balancing the out-of-trim longitudinal and lateral moments usually attendant to the high flap deflections and high powers required for low-speed flight uses up so much control power that little, if any, control power is left over for maneuvering.

3. This lack of maneuvering control power occurs at precisely that condition where a maximum of controllability is most needed: throughout the landing and take-off operations where the avoidance of obstacles assumes critical importance.

The magnitude of this low-speed control problem has become so great that many V/STOL aircraft are presently limited in their landing and

take-off performance, not by lack of lift or power, but by lack of control. A pilot usually will not use up the full performance potential of an aircraft unless he can do so with complete confidence in his ability to control it at its performance extremes. Where adequate low-speed control is not available, this confidence simply does not exist; and the pilot will restrict the aircraft's performance envelope accordingly.

While such schemes as tail rotors, tail fans, tail jet deflectors, pressure jets, and cyclically controllable propellers have all been tried in an attempt to cope with this problem, the weight, cost, unreliability, and complexity of these devices have defeated the primary objective of the V/STOL aircraft itself: a fast, simple, and economic supplement to the helicopter.

DESCRIPTION OF TEST ITEMS

ROBERTSON ULTRA-LOW-SPEED CONTROL SYSTEM

The Robertson Ultra-Low-Speed Control System is a light, simple, and effective means of generating the control powers required for low-speed maneuvering V/STOL flight. The system consists of a set of small aerodynamic control surfaces positioned directly behind the propeller and permanently connected to the airplane's primary flight control system. Being completely immersed in the propeller slipstream, these surfaces depend on slipstream dynamic pressure rather than on free stream dynamic pressure for the generation of control power. Therefore, they achieve their optimum effectiveness exactly where it is most needed: at the high powers and the low airspeeds associated with V/STOL landing and take-off maneuvers.

Figure 1 illustrates the U. L. S. configuration that was selected for the test covered by this report.

Deflection of the control surface creates an aerodynamic force normal to the surface, the control moment thus developed being equal to the magnitude of this aerodynamic force times its distance from the airplane center of gravity. Collective deflection of the horizontal surfaces produces pitch control, differential deflection of the horizontal surfaces generates roll control, and deflection of the vertical surfaces provides yaw control.

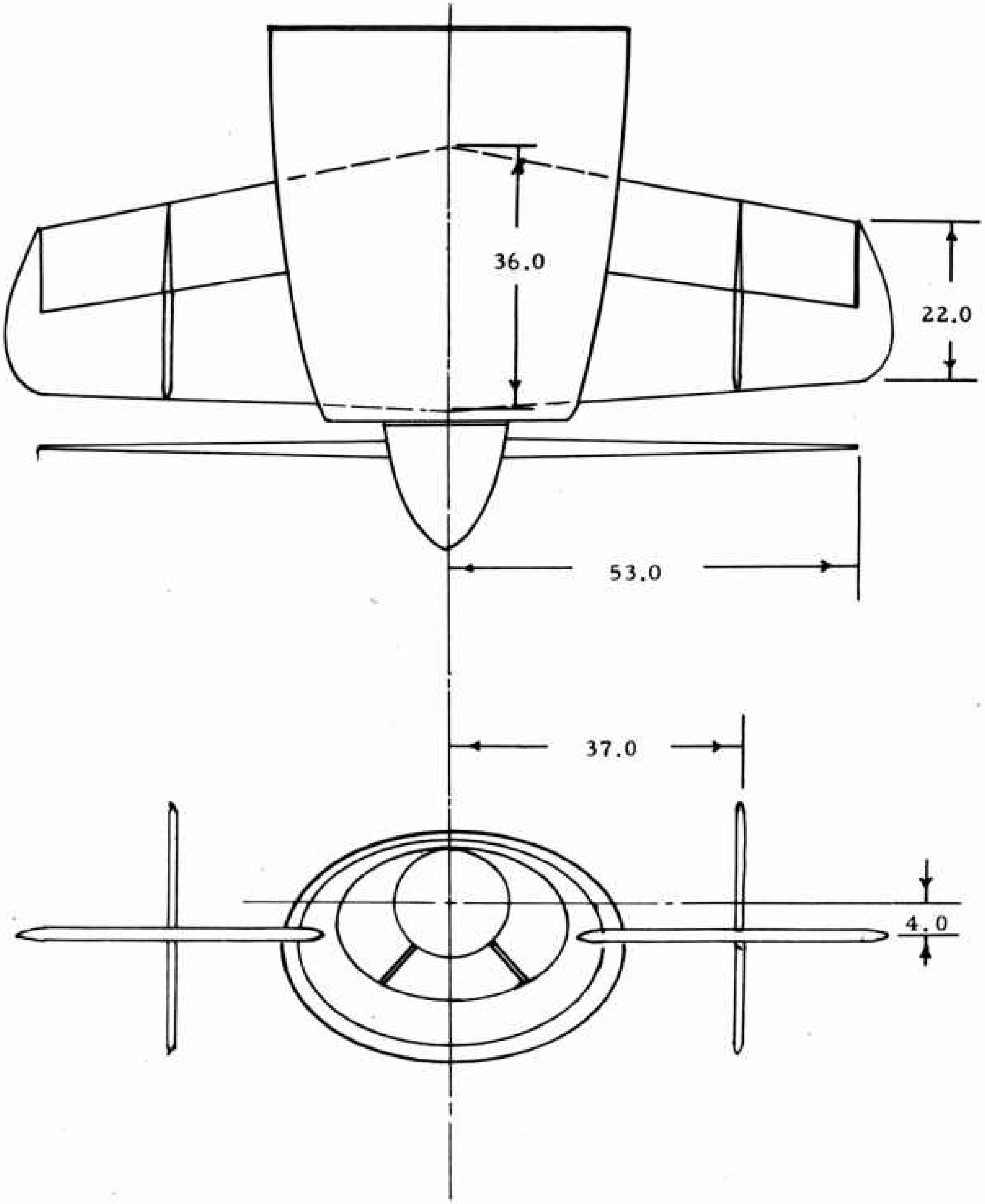

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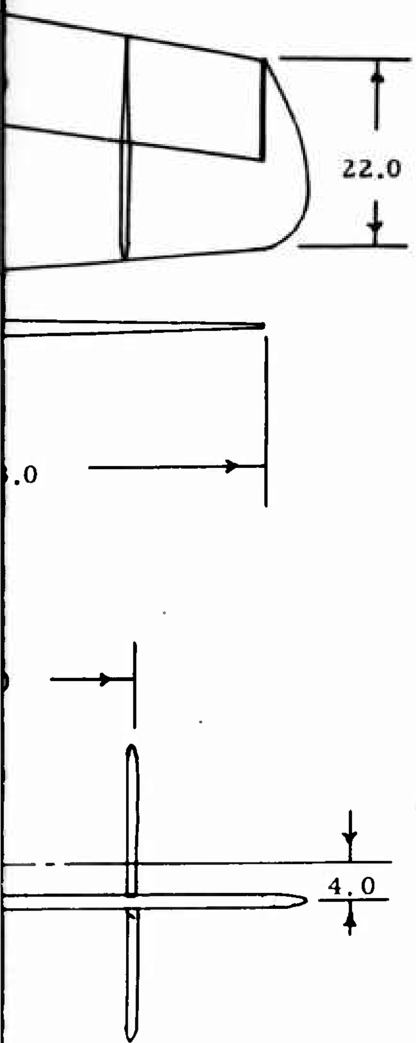
Figure 1. U. L. S. Configuratic



U. L. S. SYSTEM PHYSICAL CHARACTERISTICS

U. L. S. Horizontal Surface

Airfoil section	NASA 0009
Total area (theoretical)	21.40 sq. ft.
Total area (actual exposed)	11.40 sq. ft.
Span	8.85 ft.
Aspect ratio	3.64
Taper ratio	0.415
Sweep of c/4	0 degrees
Dihedral	0 degrees
Root chord	3.00 ft.
Tip chord	1.83 ft.
Elevator type	Plain unsealed flap
Elevator area	5.13 sq. ft.
Elevator travel	± 45 degrees
Collective for pitch control	± 30 degrees
Differential for roll control	± 30 degrees
Distance of U.L.S. aerodynamic center from airplane center of gravity (at 37 percent mean aerodynamic chord)	7.16 ft.
Distance of U.L.S. aerodynamic center from propeller plane	1.10 ft.

U. L. S. Vertical Surface

Airfoil section	NASA 0009
Total area	7.5 sq. ft.
Span	2.5 ft.
Aspect ratio	1.67
Rudder type	Plain unsealed flap
Rudder area	3.0 sq. ft.
Rudder travel	± 30 degrees
Distance of U.L.S. aerodynamic center from airplane center of gravity (at 37 percent mean aerodynamic chord)	6.75 ft.
Distance of U.L.S. aerodynamic center from propeller plane	1.15 ft.

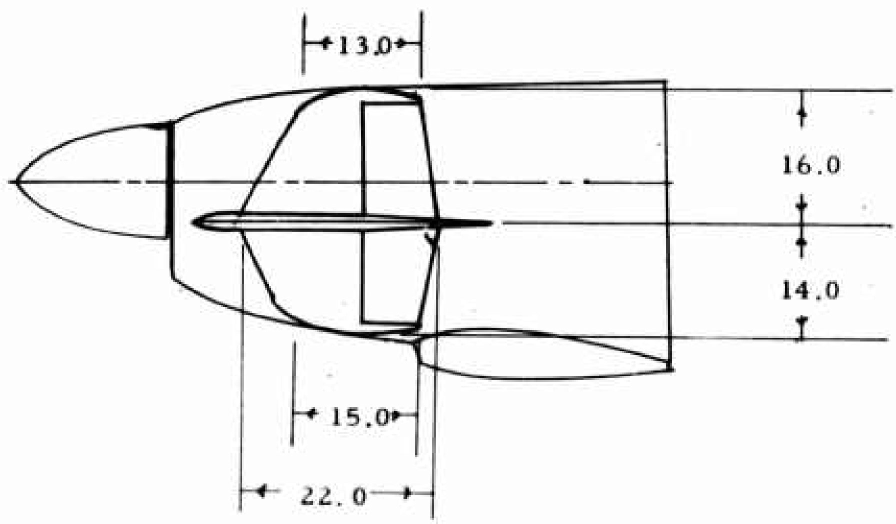


Figure 1. U. L. S. Configuration Used For Test Program.

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Since the U. L. S. surfaces mechanically and aerodynamically resemble a conventional empennage, no time lags, nonlinear control responses, or unusual hinge moment characteristics were expected. For this reason, no artificial "feel" or "boost" systems were employed.

The system thus selected was designed to have a level of complexity equal to that of a conventional empennage. The U. L. S. surfaces were attached to the engine mount of the test airplane with two bolts.

"SKYSHARK" TEST VEHICLE

The general arrangement of the Robertson "SKYSHARK" STOL test vehicle is shown in Figures 2 and 3, and a table of physical characteristics is presented in Appendix I.

Figure 2. Robertson SKYSHARK Test Aircraft Equipped With U.L.S.; Flaps and Shrouds Retracted.

Figure 3. Robertson SKYSHARK Test Aircraft Equipped With U. L. S.; Flaps and Shrouds Fully Extended.

The SKYSHARK was previously designed as a four-place STOL machine and achieved its low minimum airspeeds through the vectored slipstream principle. This principle is implemented by the installation of an unusually large full-span trailing edge flap, which not only generates high conventional lift forces but also provides additional lift by its slipstream vectoring capability.

In order for the aircraft to maintain longitudinal trim with this large flap, the wing is also equipped with an aerodynamic device known as a shroud. This shroud extends forward of the wing, thus providing lift ahead of the wing aerodynamic center and thereby balancing the high out-of-trim nose-down pitching moments associated with large flap deflections. This, in turn, decreases the balancing tail down load required for trim.

Conventional unboosted flight controls - considered to be unusually powerful at normal speeds for an aircraft of this type - were employed throughout. Even with these powerful conventional controls, the decay of dynamic pressure with airspeed control-limited the aircraft to a minimum speed of approximately 40 m.p.h.

TEST RESULTS AND EVALUATION

GROUND TEST

The objective of the Ground-Test Program was to determine the control power generating capabilities of a typical U. L. S. The configuration described in Figure 1 was therefore installed on the fuselage (minus wings and tail) of the test airplane, and runs were conducted to determine the actual magnitude of the pitching, rolling, and yawing moments that the U. L. S. surfaces applied to the airframe at forward (taxi) speeds of 0, 10, 20, 30, and 40 m.p.h.

The air loads developed by the surfaces were evaluated through calibrated hydraulic transducers, the control moments thus generated being calculated by multiplying these air loads by their appropriate moment arms. Engine power was determined by airplane engine instruments and manufacturer power charts, while forward speed was measured by a cup anemometer. All readings were allowed to stabilize for 5 seconds before being read and recorded.

The results of this program are graphically presented in Figure 4. These curves show the actual foot-pounds of control moment generated by full displacement from neutral of the U. L. S. controls at 0, 10, 20, 30, and 40 m.p.h. at 340 horsepower. For comparison purposes, the control powers of the basic airplane's conventional controls are also presented with these data. A line representing engine torque is included in the roll power curve for informational purposes.

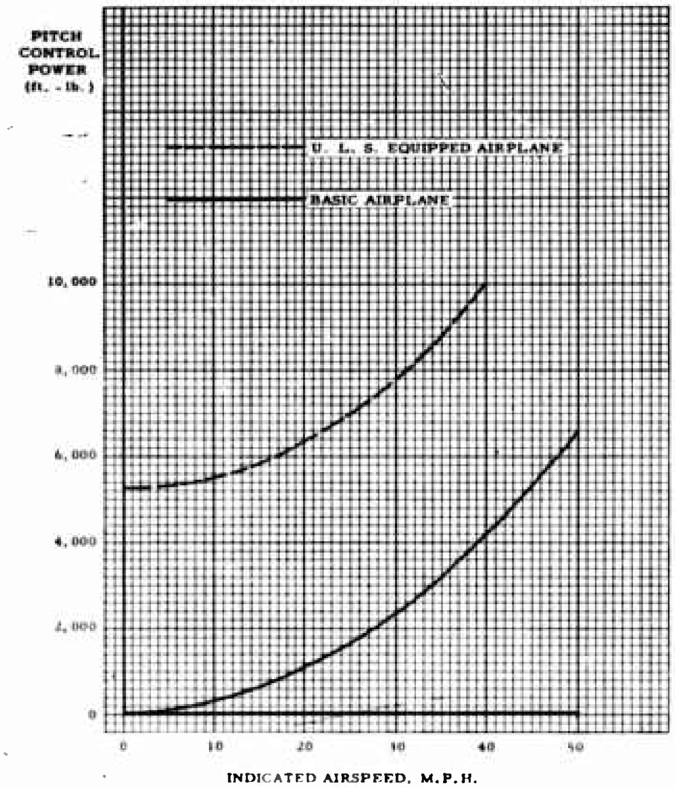
These results show that, even at zero forward airspeed, the aircraft equipped with the U. L. S. had more control power than the basic aircraft had at over 40 m.p.h., thus demonstrating U. L. S. applicability to aircraft with hovering capability. Equally interesting was the U. L. S.'s ability to generate rolling moments more than twice as large as the engine torque, thus removing the torque counteraction problem from the development of single-propeller V/STOL aircraft.

FLIGHT TEST

General

The objective of the Flight-Test Program was to determine the effect of U. L. S. installation on a typical V/STOL aircraft. This program was

S. R. Q. PITCH CONTROL POWER VERSUS INDICATED AIRSPEED;
GROUND TEST, 340 HORSEPOWER



S. R. Q. ROLL CONTROL POWER V
GROUND TEST, 340

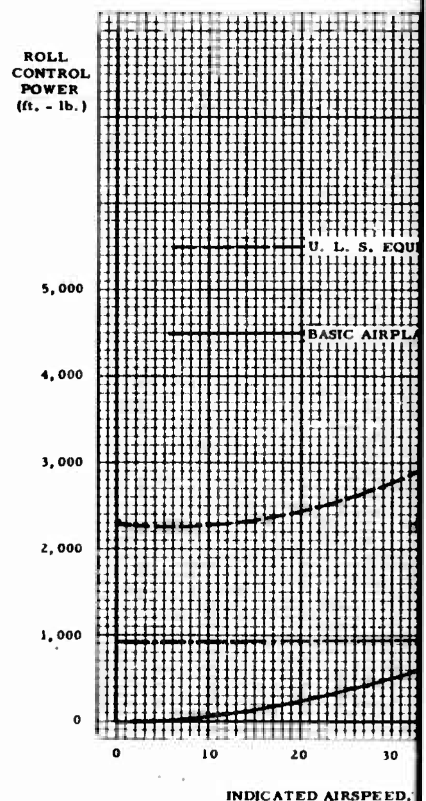


Figure 4. Ground T

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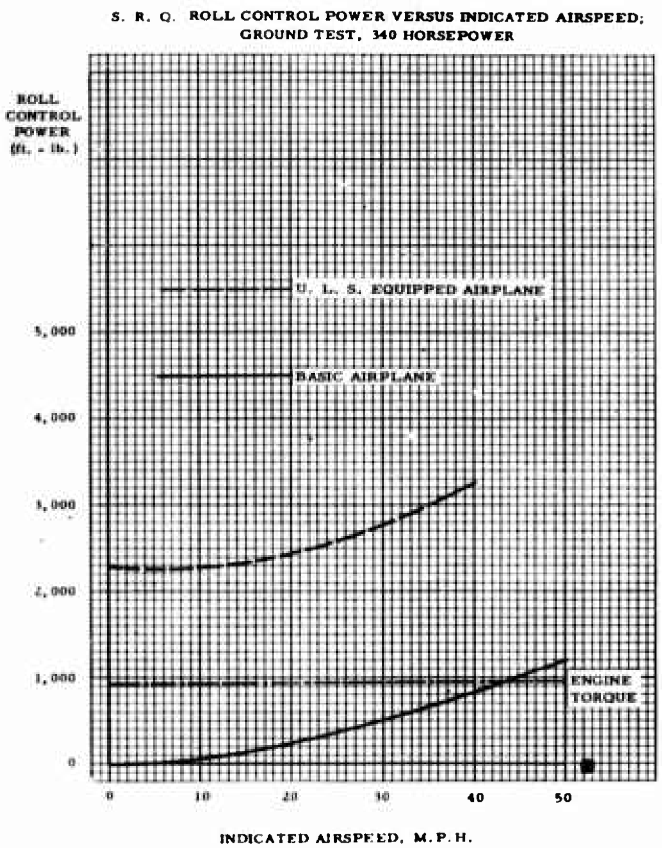

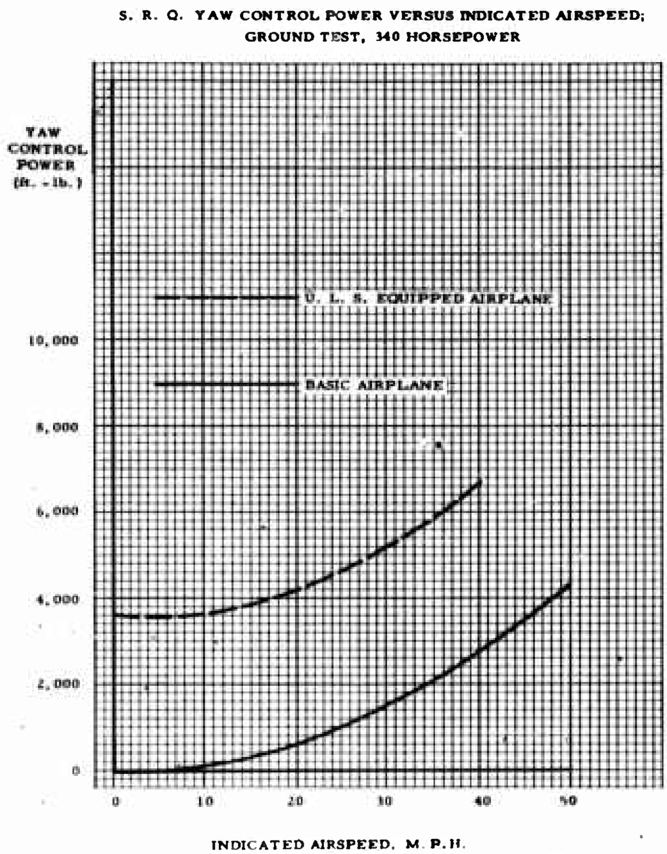

Figure 4. Ground Test Results.

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divided into five phases: stability, control, performance, handling, and maintenance. The effect of the U. L. S. installation on each of these five areas was pinpointed by the execution of identical flight operations both with and without the system installed on the airplane.

Detailed test procedures and data-reduction methods are presented in Appendix I.

Stability

Curves of the longitudinal static stick-fixed and stick-free stability of the basic airplane and the U. L. S. equipped airplane are presented in Figures 5 and 6. These data show the U. L. S. installation to have a negligible, though detectable, destabilizing effect on the test airplane.

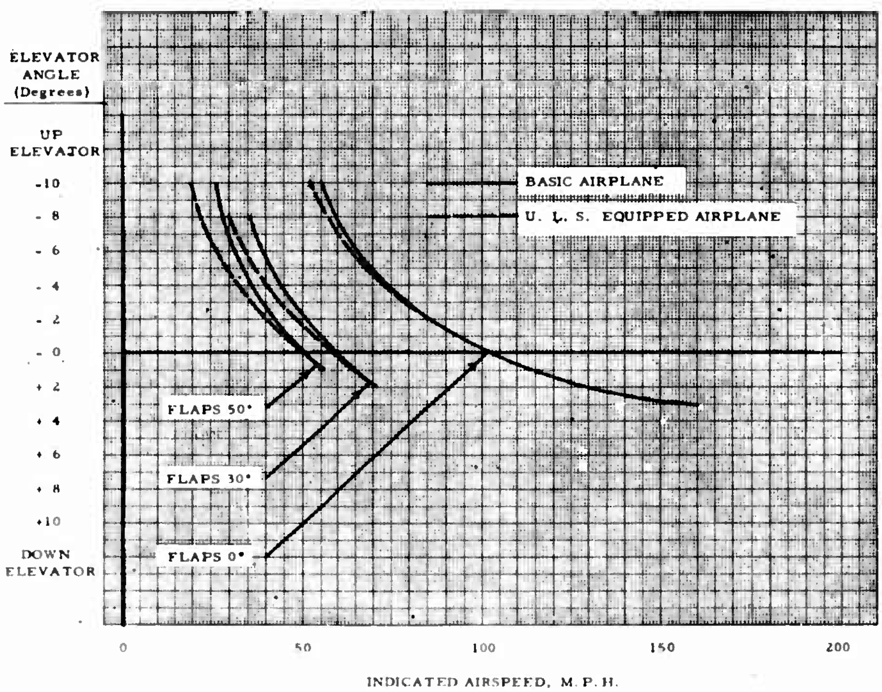

Figure 5. Static Longitudinal Stick-Fixed Stability (Elevator Angle Versus Airspeed).

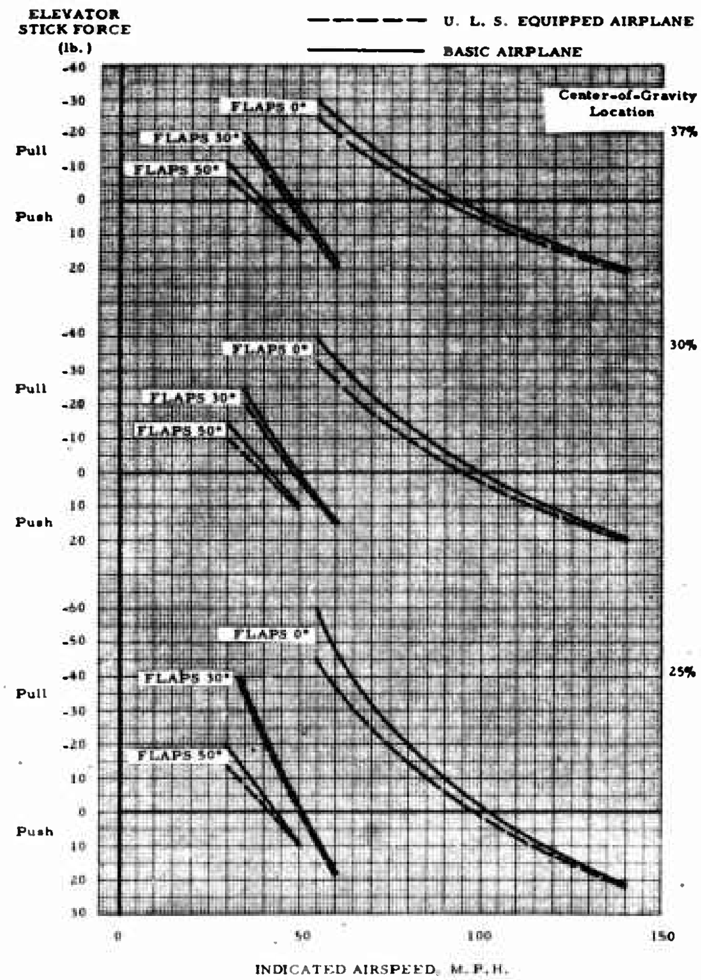

Figure 6. Static Longitudinal Stick-Free Stability (Stick Force Versus Airspeed).

Longitudinal dynamic stick-fixed short-period stability was positive and heavily damped both with and without the U. L. S. installed, as the aircraft immediately returned to its equilibrium condition following an abrupt "popping" of the control. The period of the longitudinal stick-fixed phugoid increased from 20 to 25 seconds with installation of the U. L. S., and in both cases this oscillation had weak negative damping.

Longitudinal dynamic stick-free stability was positive and heavily damped, as abrupt forcing inputs of various frequencies failed to develop any resonance or "porpoise" in the 1st, 2nd, or 3rd modes, regardless of U. L. S. installation.

Lateral static stability was unaffected by installation of the U. L. S. The lateral aerodynamic hinge moments are so low and the lateral control friction so high (6 to 8 pounds) that the lateral stick force is completely masked by system friction.

Dynamic lateral stability, also unaffected by installation of the U. L. S., exhibited a mild spiral divergence to the left and neutral characteristics to the right following the establishment of a 20 degree bank angle.

As can be seen from Figure 7, no significant change in directional static stick-fixed stability occurs with the installation of the U. L. S.

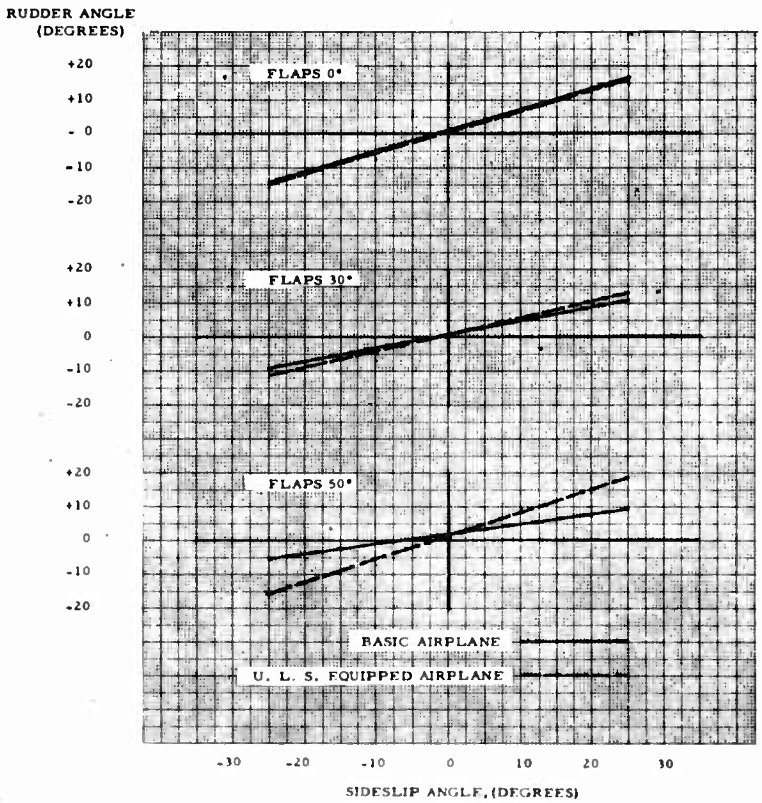

Figure 7. Static Directional Stick-Fixed Stability (Rudder Angle Versus Sideslip Angle).

Lateral/directional dynamics were evaluated both with and without the U. L. S. by attempting to force lateral, directional, "snaking", or "dutch-roll" oscillations into resonance with the control system. Under no conditions could such resonance be induced.

The U. L. S. improved the power-off stall stability by giving a definite stick-shake and prestall buffet at about 5 m. p. h. above stall speed, no stall warning of any kind being present without the U. L. S. Moreover, with the airplane's power on, the installation of the U. L. S. eliminated the tendency of the test airplane to "hang" in a stalled attitude; when the stall occurred with the U. L. S., the nose broke cleanly down to the horizon. No roll-off tendencies were observed in any case.

One of the most serious questions associated with the development of the U. L. S. was the degree to which it might adversely affect basic airplane stability. The results of the present test program demonstrate that the U. L. S. installation has a negligibly small effect on static stability and virtually no effect on dynamic stability. Since the test installation may be considered to be fairly typical, no adverse stability effects are anticipated in applying the U. L. S. to other aircraft.

Control

The U. L. S. control-power potential indicated in the Ground-Test Program was confirmed during the flight test. Controllability improvements were sufficient to reduce the aircraft's minimum speed from a control-limited 40 m. p. h. to a power-limited 20 m. p. h. Moreover, as shown in Appendix II, the U. L. S. equipped aircraft at 40 m. p. h. had 256 percent of the pitch, 250 percent of the roll, and 280 percent of the yaw control power of the basic aircraft. Furthermore, even at 20 m. p. h., the U. L. S. equipped aircraft had more control power than the basic airplane had at 40 m. p. h.

It should be noted that the U. L. S. that was tested represented one of maximum simplicity and moderate effectiveness; indeed, its effectiveness could readily be even further increased through design refinements or through use of additional power.

Finally, as shown in Appendix II, the results of the Flight-Test Program agree reasonably well with those of the Ground-Test Program.

Summarily, then, the results of the Flight- and Ground-Test Programs indicate that the U. L. S. is capable of generating the high control powers required for V/STOL landing and take-off flight maneuvers or for operations up the backside of the power-required curve.

Performance

The difference in performance between the basic airplane and the U. L. S. equipped airplane is presented below.

Performance Item	Basic Airplane	U. L. S. Airplane	Percent Change
Maximum Speed, Sea Level, 100% Power	168 m. p. h.	168 m. p. h.	None
Maximum Speed, 10,000 Ft., 100% Power	202 m. p. h.	202 m. p. h.	None
Cruise Speed, Sea Level, 75% Power	140 m. p. h.	140 m. p. h.	None
Cruise Speed, 10,000 Ft., 75% Power	168 m. p. h.	166 m. p. h.	None
Speed for Minimum Power, Flaps 0	80 m. p. h.	80 m. p. h.	None
Speed for Minimum Power, Flaps 30	50 m. p. h.	50 m. p. h.	None
Speed for Minimum Power, Flaps 50	40 m. p. h.	40 m. p. h.	None
Minimum Speed, Flaps 0	55 m. p. h.	55 m. p. h.	None
Minimum Speed, Flaps 30	45 m. p. h.	35 m. p. h.	22%
Minimum Speed, Flaps 50	40 m. p. h.	20 m. p. h.	50%
Rate of Climb, Sea Level	1,150 f. p. m.	1,150 f. p. m.	None
Angle of Approach, Sea Level, Degrees	10	20	100%
Take-off Distance, Ground Run	168 feet	85 feet	50%
Take-off Distance, Total To Clear 50-Ft. Obstacle	440 feet	435 feet	None
Landing Distance, Ground Run	70 feet	35 feet	50%
Landing Distance, Total From Over 50-Ft. Obstacle	410 feet	288 feet	30%

Since the U. L. S. controls represent only approximately 1 percent of the total frontal area of the test aircraft, they did not appreciably affect the aircraft's high-speed performance.

The low-speed performance of the test aircraft was improved by the installation of the U. L. S. to the extent that the minimum airspeed was reduced from 40 to 20 m. p. h. , with an attendant reduction in landing and take-off distance of 50 percent. These are performance improvements normally associated with improved controllability. The reduced minimum airspeed is due first to the U. L. S. 's capability of achieving the high angle of attack (19 degrees) required for the development of maximum wing lift. This also provides more thrust lift from the engine, as the engine thrust lift component is a function of the tangent of the airplane's attitude angle. Finally, the U. L. S. further reduces minimum airspeed by adding lift to hold a high angle of attack, this upload being additive to wing lift rather than (as in the case of a conventional tail) subtractive from wing lift. It should be pointed out that these performance improvements are not due to a deficiency of the basic airplane's conventional flight control system, as this system was considered to have outstanding control power for a conventional aircraft.

The benefit of reducing minimum airspeed also has a pronounced effect on the steepness of the approach angle (gradient). The reduction in approach speed of from 40 to 25 miles per hour and the increased rate of descent of from 500 to 800 feet per minute increased the approach angle from 10 to 20 degrees. These factors permit operation into many areas that would otherwise remain closed to fixed-wing aircraft.

Perhaps more important than these specific performance benefits, however, is the extrapolation of these data to higher powers. Aircraft of the Skyshark type - fairly simple STOL machines - are no longer limited in their low-speed performance by controllability. Their low speed is now limited only by power available; given a thrust-weight ratio of near 1. 0, a new type of aircraft with instantaneous take-off (though not initially vertical) and precise maneuverability would evolve.

Handling

The pilot reaction to the handling characteristics of the test airplane was surprisingly uniform. While a handling quality evaluation of this kind is necessarily qualitative, virtual unanimity was reached in the pilot evaluation comments.

First, all the pilots that had flown the airplane without the U. L. S. agreed that the airplane's minimum airspeed was control-limited to between 40 and 50 m. p. h. , flight below this speed being unsafe because of the lack of pitch and yaw control powers.

The pilots further agreed that, with the U. L. S. installed, the aircraft was controllable all the way down to its minimum power-limited 20 m. p. h. air speed. Although the pilots believed that ample pitch and roll control power existed even at 20 m. p. h. , they felt that a further increase in yaw power would be desirable to compensate for the sudden adverse yaw generated by abrupt aileron deflections during cross-wind landings and take-offs. They believed that this increase would provide a more "balanced" feeling of controllability and maneuverability.

The pilots seemed particularly pleased with the rapid response of the airplane to control displacement at low airspeeds. No objectionable, or even detectable, time lags, "nulls", nonlinear control responses, or "jumps" normally associated with low-speed controls were encountered. Control and handling characteristics at cruise and high speeds were normal, and no objections were raised concerning high-speed control sensitivity.

The magnitude of the stick forces, particularly in roll, was strongly objected to by all the pilots, and limited their maneuvering of the aircraft at low altitudes. While these high forces are due to the high friction level of the conventional flight control system and are totally unrelated to the U. L. S. installation, this fact does not diminish their undesirability. Yaw and pitch control forces were considered acceptable, though most pilots expressed mild surprise at the maintenance of these stick forces even at low airspeeds. This, of course, is due to the fact that even when the airplane is at low speed, the U. L. S. surfaces are exposed to the high-speed flow regime of the propeller slipstream.

The pilots appeared pleased with the lack of trim-changes required following changes in the power (such changes being virtually nonexistent in roll and yaw, and very slight in pitch). Also the ability of the shrouds to balance out practically all of the nose-down pitching moment associated with flap deflection was approved. However, the pilots wanted to have the flaps and shrouds move simultaneously, as their independent operation required too much pilot attention.

While the lack of any stall warning was objected to in the basic airplane, stall-behavior and stall-warning characteristics were considered normal with the U. L. S. equipped airplane.

Most of the pilots commented favorably on the stability of the U. L. S. equipped aircraft. All the pilots strongly preferred the tricycle landing gear for short field operations. None of them objected to the effect of the U. L. S. surfaces on the pilot's vision.

Summarily, the pilots in general seemed pleased with the handling qualities of the U. L. S. equipped airplane, primarily objecting only to the inordinately high lateral-control system friction inherent to the basic airplane itself.

Maintenance

Although the period of testing was limited to approximately 20 hours of flying time, no unusual resonance, vibration, flutter, or erosion characteristics resulted from the U. L. S. installation.

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APPENDIX I

PHYSICAL CHARACTERISTICS OF MODEL SRQ SKYSHARK

WING

MAIN BEAM

Section	Modified NACA 23012
Type	Semicantilevered
Area	294.0 sq. ft.
Span	43.0 ft.
Aspect ratio	6.66 ft.
Root chord	6.8 ft.
Tip chord	6.8 ft.
Mean aerodynamic chord	6.8 ft.
Sweep of the 25 percent chord line	0 degrees
Taper ratio	1.0
Twist	0 degrees
Incidence	$2\frac{1}{2}$ degrees
Dihedral	$2\frac{1}{2}$ degrees

FLAP

Section	40 percent chord RDC
Type	Nonarticulated double slotted flap
Area	67.2 sq. ft.
Span	32 ft.
Root chord	2.4 ft.
Tip chord	2.4 ft.
Mean aerodynamic chord	2.4 ft.
Taper ratio	1.0
Deflection	70 degrees
Operation	Electrical
Integration	Shrouds

SHROUD

Section	25 percent chord RDC
Type	Leading edge balance
Area	60 sq. ft.
Span	40 ft.
Root chord	1.5 ft.
Tip chord	1.5 ft.
Mean aerodynamic chord	1.5 ft.
Deflection	1.34 ft. forward, 0.5 ft. upward
Operation	Electrical

AILERON

Section	NACA 0012
Type	External airfoil
Area	33 sq. ft.
Span	40.0 ft.
Root chord	0.83 ft.
Tip chord	0.83 ft.
Mean aerodynamic chord	0.83 ft.
Deflection	Plus 30 degrees, minus 30 degrees
Operation	Conventional

EMPENNAGE

HORIZONTAL TAIL

Section	NASA 63-015
Type	Horn balanced, 50 percent balance
Total area	70 sq. ft.
Span	20 ft.
Root chord	4.35 ft.
Tip chord	2.70 ft.
Mean aerodynamic chord	3.50 ft.
Aspect ratio	5.75
Taper ratio	0.5

Dihedral	0.0
Tail length	18.75 ft.
Tail volume coefficient	0.657
Elevator area	42.0 sq. ft.
Elevator travel	Plus 10 degrees, minus 10 degrees (±)
Elevator tab	Electrically-operated trim tab

VERTICAL TAIL

Section	NASA 63-015
Type	Horn balanced, 20 percent balanced
Total area	38 sq. ft.
Span	6.66 ft.
Root chord	8.5 ft.
Tip chord	2.0 ft.
Mean aerodynamic chord	10.5 ft.
Aspect ratio	1.17
Taper ratio	0.19
Tail length	17.1 ft.
Tail volume	0.325
Rudder area	15.2 sq. ft.
Rudder travel	± 30 degrees
Rudder tab	Electrically-driven trim tab

FUSELAGE

Length	32.0 ft.
Height	10.0 ft.
Width	4.0 ft.
Cabin length	12.0 ft.
Cabin height	5.0 ft.
Cabin width	4.0 ft.
Fuselage construction	All welded steel tube, 4130 steel, covered with .025 aluminum skin
Windshield	.250 plexiglas
Windows	.1875 plexiglas
Canopy	.250 plexiglas

LANDING GEAR

Type	Fixed tricycle, power brakes, power steering
Nose gear	Electrol air-oil
Main gear	Leaf-spring

PROPULSION

Powerplant	Experimental left-hand turning Lycoming GSO 480 B1A6 equipped with dual oil system, water injection.
Propeller	Hartzell 106" diameter three-blade full-feathering Model 93Z20, constant speed.

COMMUNICATIONS

Aircraft Radio Corporation Type 15 F Omni Receiver (V.H.F.)
Aircraft Radio Corporation Type 21A A. D. F.
Aircraft Radio Corporation Type 210 Transmitter (V.H.F.)

APPENDIX II

FLIGHT TEST PROCEDURES AND DATA REDUCTION

General

All engine power, airspeed, altitude, rate of sink/climb, and time data were extracted directly from the aircraft's primary instruments. These data were visually observed and manually recorded. Remote position indicators were used to measure elevator, rudder, and aileron deflections; yaw angles were determined from a calibrated yaw vane, and interval times were recorded from a stopwatch. Stick forces were read directly from a spring scale, and angles of airplane rotation were measured directly from the artificial horizon and directional gyro. While the aircraft's primary instruments had previously been calibrated outside the airplane, substantial position errors had been discovered by pacing the test aircraft with other aircraft and with automobiles. Airspeed position errors of 5 percent were encountered at 70 m.p.h. or above, while errors (conservative) of up to 30 percent were encountered at approximately 20 m.p.h. For all the low-speed runs, therefore, speeds were determined by pacing the test airplane with an automobile through an upwind run and a downwind run in winds of less than 5 m.p.h. The low-speed results obtained are thus believed to be accurate to within 2 m.p.h.

Stability

The longitudinal, lateral, and directional stability characteristics of the test aircraft were evaluated both with and without the U. L. S. under cruise conditions (flaps 0 degrees), take-off and approach conditions (flaps 30 degrees), and landing conditions (flaps 50 degrees).

Longitudinal static stick-fixed stability was evaluated by measuring the elevator angle required to hold various airspeeds ranging from Vstall to Vmax. Longitudinal static stick-free stability was evaluated at 25 percent, 30 percent, and 37 percent mean aerodynamic chord center-of-gravity positions by trimming the aircraft at a selected airspeed (100 m.p.h. for flaps 0 degrees, 50 m.p.h. for flaps 30 degrees, 40 m.p.h. for flaps 50 degrees) and then by measuring with a spring scale the stick force required to hold various airspeeds from Vstall to Vmax. The center of gravity was changed by ballasting up to 180 pounds of lead under the engine mount. Longitudinal stick-fixed dynamic stability (short period) was determined by trimming the aircraft at its selected airspeed as noted above,

and then sharply "popping" the stick and observing its behavior. Longitudinal stick-fixed dynamic stability (long period) was measured by determining the period of the slow oscillations following a reduction in airspeed from a trimmed condition of 20 percent. The first, second, and third modes of longitudinal stick-free dynamic stability were explored by deliberately attempting to force a resonant longitudinal oscillation (porpoise) into the airplane by applying various input frequencies into the control system.

Lateral static stick-free stability was investigated by measuring the stick force required to hold various aileron deflections at the above specified cruise, take-off and approach, and landing conditions. Lateral dynamic stick-fixed and stick-free stability were similarly evaluated for the above conditions by placing the aircraft into a 20 degree bank first to the left and then to the right and by observing its ensuing behavior. All lateral tests were conducted with the rudder held in the neutral position.

Directional static stick-fixed directional stability was determined by recording the rudder angle required to hold various sideslip angles at the cruise, take-off and approach, and landing conditions. Dynamic directional stability was also investigated by sideslipping the aircraft to the right and left to its fullest extreme of rudder travel and then by releasing the rudder pedal and observing the resultant behavior. Generally the wings were held level for all directional runs.

Lateral-directional dynamics were studied in attempting to force input control movements at various frequencies to produce lateral oscillations, directional oscillations, and "snaking" or "dutch-roll" coupled oscillations.

Stall stability was evaluated by entering the stall condition at the standard rate of entry (1 m.p.h. per second) until the stick was completely back against its stop. This was repeated for the cruise, take-off and approach, and landing flap conditions both at zero power and at climb power (320 horsepower). The elements evaluated and recorded were the stall warning, the stall buffet, the stick force, the pitch characteristic, and the roll-off tendency.

Control

The control power effect of the U. L. S. was determined by measuring the difference in the time required to rotate the basic airplane and the U. L. S. equipped airplane through a specific angle after full-control

displacement. Since the dynamics of rigid bodies require that the angle through which a body is rotated (Θ) depends on the control moment applied (M) and its duration of application squared (t^2), and since both the basic and the U. L. S. equipped aircraft are rotated through the same angle (Θ), it is clear that:

$$\Theta = (f)\ M,\ t^2 \quad \text{and}\ \Theta_{uls} = \Theta_{basic}, \quad \text{then}\ M_{uls}\, t^2_{uls} = M_{basic}\, t^2_{basic}$$

and $$\frac{M_{uls}}{M_{basic}} = \frac{t^2_{basic}}{t^2_{uls}} .$$

Thus, the increase in control power of the U. L. S. equipped aircraft is inversely proportional to the squares of the time required to rotate the aircraft through a specific angular displacement.

Accordingly, control power runs were made with the flaps at 0 degrees, 30 degrees, and 50 degrees; at trim speeds of 100, 50, and 40 m.p.h. respectively; at a weight of 4,200 pounds located at 37 percent mean aerodynamic chord; and at a constant engine setting of 340 horsepower.

Pitch control power was measured by recording the time required to pitch the airplane up through a 30 degree angle. The aircraft was trimmed at its test condition, and then the stick was sharply pulled to its aft extreme as fast as possible. The time required for the aircraft to reach a 30 degree attitude angle was recorded from a stopwatch. Pitch angle was observed directly from the airplane's artificial horizon. This procedure was repeated twice for each test condition.

Roll-control power was similarly determined by trimming the aircraft at its test condition and gently rolling the aircraft to the right. As soon as a bank angle of 22.5 degrees was reached, the control wheel was sharply and fully reversed, and the time for the aircraft to roll over to a 22.5 degree left bank was measured. This procedure was repeated three times in each direction for each test condition. The rudder was held in a locked position for these runs.

Yaw control power was determined by measuring the time required to yaw the airplane through a 30 degree angle. The aircraft was gently yawed to the right until the yaw vane showed a 15 degree angle, after which the pedals were sharply and fully reversed. The time required to yaw over to 15 degrees left was recorded from the stopwatch. This procedure was repeated three times in each direction. The wings were held level for these runs.

Performance

A brief comparative performance test program was conducted to determine the performance difference between the basic airplane and the U. L. S. equipped airplane. Test runs were made at a gross weight of 4, 200 pounds at 37 percent mean aerodynamic chord under sea-level standard conditions. Test procedures were conducted in accordance with AGARD Flight Test Manuals I and II.

Airspeeds, altitudes, rates of climb, and engine power settings were read directly from the aircraft's primary flight instruments. Since comparative rather than absolute data were of primary importance in this test series, no corrections were applied to the test data.

Landing and take-off ground runs were visually marked and measured by ground observer personnel. Take-off distance over a 50-foot obstacle was determined by marking and measuring the distance at which the aircraft sharply leveled off after reaching an indicated altitude of 50 feet. Landing distance over a 50-foot obstacle was determined by having the airplane execute its landing approach over the runway boundary at an altitude of 50 feet and then by measuring the distance from the runway boundary required for the airplane to land and to come to a complete stop. Three landing and take-off runs were made under conditions of almost absolute calm (under 3 m. p. h. winds).

Handling Characteristics

Handling characteristics were compared between the basic and the U. L. S. equipped aircraft. This evaluation, though necessarily qualitative, is a valuable indication of the pilots' reactions to the U. L. S. control system. Five pilots participated in this program, two of whom were Army graduate test pilots, two of whom were professional civilian pilots with extensive rotary- and fixed-wing experience, and one of whom was a graduate aeronautical engineer with moderate (less than 250 hours) flight experience.

Elements investigated were those which would logically be affected by the installation of the U. L. S. control system. Evaluation of other handling characteristics not related to the flight operation of the U. L. S. is beyond the scope of this report.

APPENDIX III

FLIGHT-TEST CONTROL-POWER RESULTS

Presented below are the times required to rotate the aircraft through specified angles following a full application of aircraft flight controls. The times are based on a three-run average at 340 horsepower.

a) Time to pitch up through 30 degrees

Flight Condition	Time Required for 30 degrees: Without U. L. S.	With U. L. S.
Flaps 0 degrees, Vtrim = 100 m.p.h.	too violent	too violent
Flaps 30 degrees, Vtrim = 50 m.p.h.	3.5 seconds	too violent
Flaps 50 degrees, Vtrim = 40 m.p.h.	4.0 seconds	2.5 seconds

b) Time to roll through 45 degrees

Flight Condition	Time Required for 45 degrees: Without U. L. S.	With U. L. S.
Flaps 0 degrees, Vtrim = 100 m.p.h.	1.5 seconds	1.5 seconds
Flaps 30 degrees, Vtrim = 50 m.p.h.	2.5 seconds	2.2 seconds
Flaps 50 degrees, Vtrim = 40 m.p.h.	3.9 seconds	2.45 seconds

c) Time to yaw through 30 degrees

Flight Condition	Time Required for 30 degrees: Without U. L. S.	With U. L. S.
Flaps 0 degrees, Vtrim = 100 m.p.h.	2.5 seconds	2.5 seconds
Flaps 30 degrees, Vtrim = 50 m.p.h.	8.5 seconds	4.0 seconds
Flaps 50 degrees, Vtrim = 40 m.p.h.	10.0 seconds	6.0 seconds

Flight-Test Control-Power Difference

Presented below is a table showing the difference in the control-power measured in flight between the basic and the U. L. S. equipped aircraft. As outlined in the Test Procedure section (Appendix II, "Control"), control power is inversely proportional to the time of the airplane rotation squared;

thus, for the minimum speed condition of Flaps 50 degrees, Vtrim of 40 m.p.h.,

$$\frac{\text{Pitch Power of U.L.S. Airplane}}{\text{Pitch Power of Basic Airplane}} = \frac{t^2 \text{ basic}}{t^2 \text{ uls}} = \frac{4.0^2}{2.5^2} = \frac{16.00}{6.25} = \underline{\underline{256 \text{ percent}}}$$

$$\frac{\text{Roll Power of U.L.S. Airplane}}{\text{Roll Power of Basic Airplane}} = \frac{t^2 \text{ basic}}{t^2 \text{ uls}} = \frac{3.90^2}{2.45^2} = \frac{15.20}{6.00} = \underline{\underline{250 \text{ percent}}}$$

$$\frac{\text{Yaw Power of U.L.S. Airplane}}{\text{Yaw Power of Basic Airplane}} = \frac{t^2 \text{ basic}}{t^2 \text{ uls}} = \frac{10.0^2}{6.0^2} = \frac{100}{36} = \underline{\underline{280 \text{ percent}}}$$

Ground-Test Control-Power Difference

Presented below is a table showing the difference in control power as measured in the ground test between the basic and the U.L.S. equipped aircraft at an airspeed of 40 m.p.h. and at 340 horsepower. Basic airplane control power data are extracted from previous wind tunnel and flight tests of Reference 1.

$$\frac{\text{U.L.S. Pitch Power}}{\text{Basic Pitch Power}} = \frac{10{,}000 \text{ ft.-lb.}}{4{,}200 \text{ ft.-lb.}} = \underline{\underline{238 \text{ percent}}}$$

$$\frac{\text{U.L.S. Roll Power}}{\text{Basic Roll Power}} = \frac{2{,}500 \text{ ft.-lb.}}{750 \text{ ft.-lb.}} = \underline{\underline{334 \text{ percent}}}$$

$$\frac{\text{U.L.S. Yaw Power}}{\text{Basic Yaw Power}} \quad \frac{6{,}600 \text{ ft.-lb.}}{2{,}600 \text{ ft.-lb.}} \quad \underline{\underline{230 \text{ percent}}}$$

Comparison between Ground-Test and Flight-Test Differences in Control Power due to the Installation of the U.L.S. Flight-Control System

Control power of U.L.S. equipped airplane as compared to the basic airplane, 40 m.p.h., flaps 50 percent, 340 horsepower is shown below.

	Ground-Test Data	Flight-Test Data
Pitch Control Power	238 percent	256 percent
Roll Control Power	334 percent	250 percent
Yaw Control Power	230 percent	280 percent

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V/STOL aircraft. This system consists of a set of small aerodynamic control surfaces placed in the propeller slipstream immediately behind the propeller and permanently connected to the airplane's conventional flight control system.

Stability and handling characteristics were not appreciably affected by the new system. The system increased the control power at 40 m.p.h. to 256 percent in pitch, 280 percent in yaw, and 250 percent in roll of the basic airplane values. This in turn permitted a reduction in minimum airspeed from a control-limited 40 m.p.h. to a power-limited 20 m.p.h.,reduced landing and take-off distances by 50 percent and increased the slope of the glide angle from 10 to 20 degrees.

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